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HUMUS IN CALIFORNIA SOILS

BY
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HUMUS IN CALIFORNIA SOILS.

By R. H. LOUGHridge.

INTRODUCTION.

Examinations of California Soils.

Information and data regarding the nature of the soils of the State have been obtained through the physical and chemical analyses of thousands of samples taken according to our directions and sent to our laboratory by farmers throughout California; by the examination of samples of a few feet in depth taken by us or other members of the station staff; and of one hundred soil columns taken to depths of ten or twelve feet from each of the main soil regions of the State, chiefly by the author and his assistant, the late F. E. Johnson.

It has been the policy of the California Experiment Station, from the time when Professor Hilgard established it in 1875 to the present time, to respond to the call of farmers for information regarding problems of the farm in all of its branches, and especially those of the soil and its products. The examination of soils has been free to the farmer, and during these years many thousands of samples of soil have been sent to us by them to ascertain whether there be a lack of plant food and a need of fertilizers, whether alkali salts be present and how gotten rid of, or whether there be some other causes of infertility. The samples were for the most part taken according to our directions, and examined as to their physical properties, and as to the approximate amount of humus, lime, and phosphoric acid, and sometimes of potash, short methods for these determinations having been adopted. Where alkali was found to be present in any appreciable amount, the percentage of each salt was determined by a regular analysis.

These examinations of soils that came from every part of the State, together with such personal visits as Professor Hilgard and the author were able to make to the main agricultural regions, gave an excellent insight into the agricultural conditions of every part of the State; which has been of very great importance in our work and a special help toward the completion of a soil map of the State, there being no funds available for the prosecution of a soil survey.

While this work consumed much of the time that we would have preferred to give to research, we believe that it has been of value to those concerned and especially to the station, by bringing it and the farmer into close touch with each other.

The Nature of Humus and its Formation.

The name humus should not be applied to all of the vegetable matter of the soil in all stages of decay, as many seem to think, but only to a peculiar product of partial decay of vegetable and animal matters

brought about under conditions of moisture, warmth, a limited amount of air and in the presence of lime. Until humification of the leaves, roots and other plant débris takes place the beneficial effects of humus itself are not obtained, and the material, while loosening the soil (sometimes injuriously), is practically inert as far as enriching the soil with its nitrogen and mineral elements is concerned. This was shown by the experiments of Professor Hilgard, carried on through a period of two years. (Soils, page 359.)

Humus contains all of the decomposition products of both vegetable and animal matters, and therefore includes at least minute quantities of amido, amin, and purin compounds, most of which are beneficial and some are injurious to vegetation.

Humus is so thoroughly disseminated in the soil that its presence is noticeable only in the dark color it gives when in large amounts. It is black or brown in color, resembling charcoal in its lightness and porosity as well as in its destructibility by fire. It is colloidal in nature and though derived from vegetable matter, it has lost all of the fibrous and cellular structure of plants. It is highly absorbent of gases and of moisture in the latter case, swelling to eight to fourteen times its dry volume.

Humus has no definite composition beyond the fact that it is made up of the same elements that enter into the composition of plants—carbon, oxygen, hydrogen, nitrogen, and some mineral elements. The proportion of carbon is, however, greater than in plants because of the partial decay. Humus is really a mixture of compounds in proportions that vary with the nature of the substance from which it was obtained, and from a mixture of different substances in the soil. This is especially true with regard to the nitrogen—the most valuable element in humus. Some organic substances are almost lacking in nitrogen and yield a humus containing but little of it, while, on the other hand, a humus may be extremely rich in nitrogen because derived from substances very rich in that element.

In a soil humus is usually combined with lime and other elements as humates, and is then not soluble in water, but is dissolved by a solution of caustic alkali and of carbonate of soda, thus giving rise to the name “black alkali.” In soils that are weak in lime it often occurs as free humic acid, and is then soluble in water and causes injurious acidity in soils, which must be counteracted by the application of lime. By the action of air and bacteria it is slowly destroyed and carbonic acid, water and ammonia are produced. Free humic acid is frequently produced by the growing of lime-loving plants, such as alfalfa and other legumes, the lime being absorbed by many successive crops and the humus left behind as humic acid. This has taken place in the Eel River Valley soils of Humboldt County, California, and only the application of lime has restored the land to its former fertility.

Amount of Humus Formed from Vegetable Matter. With regard to the amount of humus formed from the decay of vegetable matter, Professor Hilgard says (Soils, page 128): "Only very general and indefinite estimates can be given of the amount of humus formed from a given amount of vegetable matter, since these must vary according to the conditions under which the transformation occurs. The greater or less access of air and of moisture, the temperature and pressure under which the process occurs, will modify very materially the quantitative as well as the qualitative result. In the hot, arid regions the fallen leaves may wholly disappear by oxidation on the surface of the ground, while under humid conditions they are mostly incorporated with the surface soil. If we assume that in the humification of plant débris no nitrogen is lost, it would seem that in the humid region one part of normal soil humus might be formed from five to six parts of dry plant débris; while in the extreme régime of the arid regions from eighteen to twenty parts of the same would be required. But as most probably some nitrogen is lost in the process of humification, a considerably larger proportion of original substance may be actually required."

Professor Snyder of the Minnesota Experiment Station by his experiments (Bulletin 53) obtained the following results: One part of humus to 32.7 parts of fresh cow manure, or 24.5 parts of green clover, or 10.8 of meat seraps; the humus of the cow manure contained 6.16 per cent of nitrogen, that of the clover 8.24 per cent and that of meat scraps 10.96 per cent. Oat straw and sawdust remained in the ground apparently unchanged for more than a year, but finally gave one part of humus for 5.5 parts of straw and for 9.5 of sawdust, respectively; the humus of the straw had 2.5 per cent of nitrogen and that of the sawdust only 0.3 per cent. In the drier soils of California the straw and sawdust would doubtless remain unchanged for several years.

Value of Humus.

The great value of humus to the soils of this State is not as well recognized generally by farmers as it should be, and they probably do not fully realize that by maintaining a proper supply in the soil through a careful system of green-manuring they will avoid the expense of hundreds of dollars worth of nitrogen, that most expensive of fertilizers, and at the same time keep the soil in a splendid physical condition not produced by fertilizers alone.

Potash, phosphoric acid and nitrogen have their beneficial effect only in maintaining the growth and productiveness of plants and do not affect the soil itself materially; lime influences the structural formation of the plant, the character of the fruit, the physical condition of soils, and neutralizes any acid condition. But humus goes still farther by not only supplying important and expensive elements of food to the

plant and producing excellent mechanical conditions in the soil, but by influencing the life and activity of important bacteria. The following is a brief summary of the value of humus:

Humus Improves the Structure of Soils. It does this in clay soils by causing aggregation or flocculation of the particles of clay into a granular condition, thus producing looseness and easier tillage. The soil is thus better *aerated* and *ventilated*, and is made *warmer* for plant development. By this condition it is made more *receptive for rainfall*, permits greater freedom in the downward percolation of water, and prevents its evaporation by the sun's heat. When incorporated with loose sandy soils it occupies the spaces between the grains, thus binding the sand together, and giving better texture. By this the soil is made to hold moisture which would otherwise be lost by percolation and by evaporation; and it is made cooler in summer because of absorption and radiation of the heat from the black particles. It decreases the conductivity of a sandy soil for heat, thus preventing overheating of surface plant roots in such soils.

Humus Largely Prevents the Crusting of Soil Surfaces. One of the troubles that California farmers have to contend with is the tendency of the soil to become crusted over or compacted after a rainfall or after irrigation. This seems to be quite general throughout the State, and we believe is in part due to insufficiency of humus and of other vegetable matter which would maintain a granular structure in the soil. An intermixture of well-rotted stable or farmyard manure would also tend to prevent the crusting, but the turning under and humification of suitable green-manure crops until the amount of humus produced reached several per cent would be better and more permanent.

Humus in the Soil Absorbs Water and Water Vapor. This is due to its porosity, which gives to it a very high absorptive power. But it does this only in its diffused colloidal condition in the soil. When separated from the soil and dried at a low temperature it loses its colloidal nature and acts only as so much fine silt.

Humus Promotes Chemical Action in the Soil. The humus acts upon the inert and insoluble minerals in the soil and slowly renders their elements of plant-food available for plant use.

According to Prof. Harry Snyder of Minnesota,* it is only the humus that contains a high percentage of nitrogen that acts most energetically upon the inert mineral matter, and he designates this as "active humus," while that with low content of nitrogen he classes as "inactive humus."

Humus Contains Nitrogen and is a Nitrogen Fertilizer. Nitrogen exists in the soil partly in the free state in the air that permeates the soil mass; partly in the vegetable and animal material that has not

*See Chemistry of Soils and Fertilizers, page 100.

undergone humification; partly in the humified vegetable and animal matter in water, and hence very variable in amount from day to day and liable to be lost by drainage. That the unhumified material in the soil does not yield its nitrogen to plants until after complete humification has been shown by the experiments of Professor Hilgard, whose conclusions are as follows: "It thus appears that although the nitrogen of the unhumified organic matter constituted about 40 per cent of the total in the original soil, it would during the entire year have contributed only to an insignificant extent to the available nitrate supply; while the fully humified 'matiere noire' contributed fourteen times as much. During the growing season of four or five months the unhumified organic matter would have yielded practically nothing to the crop." (Soils, page 360.)

The humus itself then is the most reliable source of nitrogen, keeping it in reserve, to be given to the roots of plants by degrees, by ammonifying and nitrifying bacteria and at the same time when most needed, viz, in the growing season. The fertilizing value of humus depends, as has already been remarked, upon the amount of nitrogen that it contains and which may be changed to ammonia and nitrates through the agency of bacteria and given to the soil and plant. The nitrogen content naturally varies according to the nature of the materials from which the humus was formed and to any diminution that may have occurred from bacterial action or other causes, and we therefore find great differences in one and the same column of soil. Sometimes the difference is very great between one foot and the next below, for which it is difficult to account.

This humus nitrogen is not, so far as we know, directly available to plants, except in minute quantities of soluble amido compounds formed by the decay of nitrogenous matter, but becomes so through the action of ammonifying and nitrifying bacteria in the soil, which convert it into nitrates.

The humus, therefore, is a valuable source of nitrogen for plant use, and at the same time is a cheap source, because a crop of legumes can be grown at but the small expense of growing, cutting, and plowing under. The percentage of nitrogen that humus contains varies in California from a little more than one per cent in the desert sagebrush lands to as much as twenty per cent in better lands; the average is from five to six per cent.

Humus Contains Soluble Mineral Plant-food. When humus is separated from the soil and burned it leaves an ash which contains large percentages of potash, soda, phosphoric acid and lime, which while in combination with humus are regarded as being immediately available for plant use. While the amount thus contained in the soil is not large,

varying from .01 to .05 per cent of potash and of phosphoric acid, it adds very materially to the fertility of the soil, the latter percentage being equivalent to about two thousand pounds per acre-foot.

Destruction of Humus.

Humus, like all other organic substances, may be destroyed by dry decay through exposure to hot dry air, either in the immediate surface of the soil or in the portion that is stirred by the plow or cultivator. The loss each year is imperceptible and the effect is seen only after many years of cultivation, except in soils naturally weak in humus, when there is a decrease in productiveness and a tendency to form a hard crust on the surface. In Minnesota* it was found that cultivation of wheat for eight years caused a loss of 17,000 pounds of humus and 1,700 pounds of nitrogen per acre. The crop itself used 350 pounds of the nitrogen, thus leaving 1,350 as the loss due to destruction of the humus by cultivation. It was also found that summer-fallow was more destructive of humus and its nitrogen than was continuous cultivation in grain; the loss in two years by summer-fallow was 600 pounds of nitrogen or twice the amount used for two crops of wheat.

Humus in California Soils.

In California the general practice of continuous grain-growing on the same land, and especially of summer-fallow, for the past many years has resulted in the lessening of the humus content and its nitrogen in the soil by the cultivation required, and as a consequence the yields of grain have fallen off year by year. An instance of this destruction by cultivation was shown in the examination of the soil of the University Farm at Davis, which had been under continuous grain culture for thirty or more years when purchased by the University. The humus percentage of the first foot was found to be .79, with 4.55 per cent of nitrogen. The humus in the virgin soil just outside of the wheat field was 1.25 per cent and its nitrogen 5.90 per cent. This difference of .46 per cent of humus and 1.35 per cent of nitrogen, between the cultivated and uncultivated soils, indicates a loss of more than one third of the nitrogen, caused by wheat culture. This is equivalent to 18,400 pounds of humus and 1,520 pounds of nitrogen per acre. The effect of this loss of humus and its nitrogen has been seen in the falling off in productiveness and in an increased tendency of the soil to form a thin surface crust, and in other ways to so affect the physical properties of the soil as to interfere with the proper development and functions of the grain roots. The soil becomes lighter in color, more compact, poorly aerated and less retentive of moisture. Percolation of water from rainfall or irrigation is slower and evaporation from the surface more rapid, the soil becoming dry to quite a depth.

This loss of humus and its nitrogen in the surface soil is a necessary

*Bulletin No. 70, Minn. Expt. Station.

evil everywhere, for the soil must be plowed and cultivated to maintain proper conditions for high productiveness, and it is a loss more quickly felt, of course, in soils where the amount of humus is low. After many years of cultivation it will be felt in soils having a good supply of humus, but which exists only in the upper six or eight inches. It should not be felt in decreased productiveness of the crop for fifty or one hundred years in soils having a good humus content through a depth of several feet; and it would not be if proper attention were paid to the maintenance of good tilth, aeration and water supply, and to the encouragement of the penetration of the roots to the deep source of supply. Had California grain-growers treated their soils rightly during the past years and kept them in good tilth to a depth of 10 or 12 inches, the high yield of 40 to 50 bushels of wheat in early years (*e. g.*, on the sandy lands of Stanislaus County in 1879) would have been maintained to the present time, for the grain roots would have found ample supplies of nitrogen in the humus which we show in this bulletin exists to a depth of many feet. The loss of humus has, however, been severely felt in the soils of many parts of the State, not only because there was naturally but a small amount in the surface soil, but largely because of the methods of cultivation and treatment the soil has received. In fact, this shallow plowing seems to be the source of most of the trouble that comes to the farm and orchard in a country so blessed with deep and rich soils.

Humus in the Surface Foot.

The results of the soil examinations have brought out the fact that, while the supply of *potash* is as a rule very large and should not need replenishment by fertilizers for decades, and that *phosphoric acid* is generally fair in amount, except in lands that have been in wheat culture for many years, the percentage of *humus* in all surface soils except tule swamps is quite low and has required a system of green manuring to bring the land back into the best condition.

Cursory Examinations. Because of the time required to make an accurate analysis of each soil and especially as the question was chiefly as to the sufficiency or insufficiency of potash, phosphoric acid, lime, and humus, we adopted at the beginning a scale of tests by which approximate results could be reached very quickly. The results for humus were graded into "good" for 1 per cent and above, "fair" for .7 to 1 per cent and "poor" for less than .7 per cent in the surface soil. It may be of interest to give a summary of the results obtained from 1893 to 1908, the time when, because of pressure of more important work, these examinations were brought to a close.

The following table presents the results, by agricultural regions, from 1,456 soils in which the humus was determined. The percentages of "good" for those above 1 per cent, "fair" from .75 to 1 per cent, and

"poor" for less than .75 per cent of humus are given for each region, and also for the entire State.

	Number of soils examined	Good humus	Fair humus	Poor humus
Sacramento Valley -----	211	Per cent 55	Per cent 18	Per cent 27
San Joaquin Valley -----	434	24	24	52
Foothills of Sierra Nevada -----	66	59	12	29
Coast Range valleys -----	398	64	19	17
Southern California -----	347	43	23	34
Average -----	1,456	46	21	33

It will be seen from the above that more than one half of the soils of the Sacramento, Foothill, and Coast Range regions that were sent for examination by farmers of those regions had as much as one per cent of humus, though for the State at large, only 46 per cent of the 1,456 soils had that amount.

Regular Analyses of Carefully Selected Soils. From time to time, since the establishment of the station, nearly five hundred complete analyses have been made of soils chosen to represent the different agricultural regions and conditions in the State, and among the determinations was that of the exact amount of humus in the surface soil. The method of humus determination used was what is known as the Grandjeau Method as modified by Professor Hilgard. The results therefore more nearly represent actual average conditions in the soils of California. The following table shows the average percentages of humus in the soils of the several regions.

TABLE SHOWING PERCENTAGES OF HUMUS IN SURFACE SOILS.

Regions	Number of soils exam- ined for humus	Average per- centage of humus	Percentage of soils having more than 1 per cent of humus
Tules and Meadows -----	14	3.62	all
Coast Range valleys -----	91	1.69	67
Sierra Foothills -----	46	1.23	41
Sacramento Valley -----	29	1.14	50
Southern California -----	61	.94	28
San Joaquin Valley -----	67	.79	29
Desert plains and Lava-bed valleys -----	23	.51	0
General average for State -----	331	1.25	40

The general average of humus in the 331 surface soils taken from different parts of California, and supposed to fairly represent all of the agricultural regions, is 1.25 per cent. If, however, the tule marshes and the meadow lands are omitted from the calculation, then we find that the general humus percentage is 1.15. This is almost the identical humus percentage of the average of 306 soils of the arid region (1.13)

given by Professor Hilgard in his book on Soils, page 377, and embracing soils from Idaho, Arizona, Oregon, and California.

It is a peculiar fact that of the 331 soils examined only forty per cent had more than one per cent of humus in the first foot, thus showing the need for replenishment by the turning under and humification of green manure crops for a series of years.

DISTRIBUTION OF HUMUS DOWNWARD FOR MANY FEET IN CALIFORNIA SOILS.

A very marked characteristic of the soils of California is their great depth, as exemplified in the uniformity of color through a depth of several feet, their good texture affording easy penetration of plant roots often to depths of twenty and even sixty feet below the surface; abundant food available for plant use throughout these depths, an absence of any well defined subsoil except at a depth of several feet below the surface, the absence of any compact clay substratum differing from the surface foot, and the presence of humus to as much as ten or more feet. In each of these particulars the soils of this State differ from those of the humid states east of the Rocky Mountains, and because of this the methods of culture are different, and in the applications of fertilizers to the soil it is only with difficulty that they can be made to reach the feeding roots of plants.

These facts are soon realized by farmers from the East who come to the farms of California, and find that the eastern methods of cultivation will not give the best results, and must be changed to those found to be more successful. There are several striking facts regarding the humus itself in the soils of California that deserve mention and which distinguish them from the soils of the humid region of the eastern states, one of which has but recently been brought out in the examinations that are being made of the many typical twelve-foot columns from the chief agricultural divisions of the State. These facts are: *First*, the small amount of humus in the first foot of all soils, in comparison with three or more times as much in eastern soils; *second*, the distribution of the humus downward to depths of twelve and more feet in upland soils, the total of which is greater than that of the eastern soils; and *third*, the rather higher percentage of humus nitrogen in the upper feet and the distribution of the humus nitrogen throughout the twelve feet, thus giving the soils of the arid region a higher total of humus-nitrogen content than is found in the humid soils.

Bacterial Activity in the Soil. Another highly important advantage possessed by California in her soils is the fact recently brought out by Prof. C. B. Lipman of this station in his paper on the Distribution and Activities of Bacteria in Soils of the Arid Region*: "that soils of the arid region at all depths studied show ammonifying powers, which are, however, generally most vigorous in the first six or eight feet. In one case ammonification was noted in soil from a depth of fifteen feet, or adjoining the watertable * * *. As for nitrification my data present again features of striking interest. They go to prove that nitrate

*Univ. of California Publications, Agricultural Sciences, Vol. I, No. 1.

formation, like ammonification, goes on at much greater depths in soils of the arid than in soils of the humid region * * *. That nitrification is found commonly down to a depth of five or six feet in soils of the arid region. In one case a soil from an eight-foot depth showed a vigorous nitrifying power."

Professor Lipman's observations greatly emphasize the importance of having the roots of the various crops utilize the food supplies at their command at depth of many feet; for not only is there a nitrogen supply, but our investigations on the soil columns show that the amount of available phosphoric acid and of potash is large at depths of twelve and more feet.

Leveling of Lands. The existence of humus and an abundance of available plant food at depths of many feet in our soils is well and practically demonstrated by the fact that when lands are leveled and hogwallows (except in an alkali country) filled up by cutting down the hillocks of several feet height, the exposed undersoil is fully as productive and as quickly capable of producing good crops as the original surface soil. This leveling is very generally and successfully practiced in California, and especially in the reddish hogwallow lands of the eastern side of the San Joaquin Valley, before planting orchard trees. The rock-like hardpan in the bottom of the hogwallows at a depth of a few feet is broken up by a small charge of dynamite to afford good drainage, and the hillocks cut down by plowing and scraping their soils into the natural depressions. There is no unproductive or raw clay substratum similar to that of humid climates to be cut into and exposed, and which must remain for many months before being sufficiently acted upon by weathering agencies to yield even a growth of grass.

Obtaining Soil Columns. In 1883 we were asked by the California Commission to furnish a few typical soils of the State for the state exhibit at the St. Louis Exposition, and it was decided to make this feature of depth a prominent one by securing soil columns of about twelve feet in depth, each foot in the column being shown in its place in wide bottles placed one above the other and properly labeled. Eighteen of these columns were taken by us from different sections of the State and placed on exhibition. These proved to be so attractive to visitors by illustrating the nature and depth of California soils and their examination proved of such importance in establishing the presence of available plant food and of humus at great depths that we have added to the collection, and there are now one hundred and ten columns which

NOTE.—Much difficulty was experienced at the outset in securing soils to a depth of twelve feet without great expenditure of time and money, as large samples of a foot each were necessary for representatives in the soil column and for analyses. A posthole auger (made and patented by Messrs. Iwan Bros., of South Bend, Indiana) was at last found and proved to be admirably suited to the purpose; it cuts rapidly on bottom and sides and holds the soil well. Fitted with extension pipes of three foot lengths which are easily removable, the auger is made to reach any depth except when coarse gravel or hardpan is encountered.

represent the most important of the soils of the many agricultural regions of the State. These have been arranged in vertical positions in the soil museum of Budd Hall and are being examined as rapidly as possible from a chemical, physical, and biological standpoint. The results will be presented in a special report.

Distribution of Humus in Soil Columns from Each Agricultural Region.

The agricultural regions of the State comprise the Sacramento and San Joaquin valleys, forming together the central Great Valley, the Foothills lying on the western slope of the Sierra Nevada, the many Coast Range valleys and low hills among the mountain ranges along the western side of the State, the Southern California valleys and the low hills, the Desert Plain which is being brought under cultivation by the development and use of irrigation water, and the Northeastern Lava-bed valleys. A large portion of the State is too mountainous and rugged for tillage and is partly timbered with forests of redwood, pine, and other trees suitable for lumber. The redwood forests form a region of the Coast Range of mountains.

As the object of this investigation was chiefly to ascertain the extent to which humus was found in the lower depths of the soils, the soil columns were only taken from those regions whose soils are many feet in depth. The number of columns obtained was 110 from thirty-seven counties, each column intended to represent a characteristic type of land in its particular region. There are of course very many small valleys and minor soil regions that have not been included in this investigation, some of which may be taken up later and reported when the results of the chemical and physical examination of these soil columns are given to the press. The analyses of the first foot of the soils of many of these regions have already been published in the reports of this station. It is believed that the results presented in this investigation represent very well the humus conditions that prevail in the soils in general throughout the State.

The humus and nitrogen determinations given in the following pages were made successively by Messrs. F. E. Johnson, M. E. Holter, and F. H. Wilson.

Soil Columns of the Sacramento Valley.

The valley of the Sacramento River, lying between the two great mountain ranges—Sierra Nevada on the east and Coast Range on the west—and which unite on the north, covers an area of 6,200 square miles. The valley is widest on the south where it unites with the San Joaquin Valley. Within its area are four or five general and highly distinct soil regions, or types, each of which is represented by one or more soil columns in our collection, or eighteen in all.

Alluvial Lands. These border the Sacramento River and are timbered with sycamore, white oak, and ash. The soil is a dark loam with little or no change to the depth of twelve feet, as shown in the soil columns, and even deeper. Three columns were taken from the following localities: Near Cottonwood, Shasta County, by W. S. Guilford; Glenn post office, in Glenn County, east of Willows; and near Perkins, Sacramento County, by Professor George Roberts, now of the Kentucky Agricultural College. To these was added a column of the alluvium of Chico Creek, taken from the Bidwell place, at Chico, Butte County.

Clay Loams of the Valley. These reach south from near Red Bluff and occupy the central part of the Sacramento Valley. As typical of this class of soils, seven columns were obtained from the following localities: Three miles west of Tehama, Tehama County; Willows, Glenn County; J. W. Walton's place a few miles south of Yuba City, Sutter County; Woodland, Yolo County; the University Farm, Davis, Yolo County; Live Oak, Sutter County, and from near Elmira, Solano County. In each case a depth of 12 feet was reached except at Live Oak, where at 9 feet the presence of water prevented a deeper sampling.

Black Adobe Clay Soils. There are several regions of these black clays within the eastern, western, and southern parts of the Sacramento Valley. One of these reaches from southwest of Yuba City northward, passing west of Gridley and beyond Biggs. A column was taken from this belt, a few miles southwest of Yuba City, the surface soil of which contained 39 per cent of clay. Below this upper foot the color changed from black to gray. Another column was taken by F. E. Johnson from near Biggs. This contained 50 per cent of clay in its upper foot and the black color changed to gray below the third foot.

A region of black clay lies three miles east of Willows, Glenn County, whose surface foot contains 47.46 per cent clay, and the black color extends through five feet. A column of this was taken to the depth of twelve feet. Another column was taken from a body of intensely clayey and black land lying south of Dixon. It contains 61.75 per cent of clay.

Red Mesa and "Bedrock Lands." These form a wide border along the eastern and northern sides of the valley, and are characterized by usually shallow soils underlaid by either heavy compact red clays, or by cemented beds of gravel and grit, forming a hardpan or bedrock at depths of from two to five feet below the surface. Because of the shallowness of these lands, this region is represented by but three columns; one from near Sheridan, Placer County, representing the lands on the eastern side of the valley; another from the bluff of Oak Creek, southwest from Red Bluff, and one half mile west of the Corn-ing road; and still another taken by F. E. Johnson near Acampo, San Joaquin County.

HUMUS AND HUMUS-NITROGEN IN SOILS OF THE SACRAMENTO VALLEY.

	Per cent humus					Per cent humus-nitrogen in soil	
	First foot	Upper 3 feet		Twelve feet		First foot	Upper 3 feet
		Average per foot	Sum of per cents	Average per foot	Sum of per cents		
Alluvial soils -----	1.47	.92	1.47	.67	7.50	.08	.06
Black clay adobe-----	1.16	.73	2.20	.31	3.62	.06	.04
Gray clay loams-----	.95	.77	2.39	.42	5.02	.05	.05
Red mesa lands-----	.47	.30	.90	.15	1.43	.03	.02

It would naturally be supposed that because of their deep color the black clay adobe soils would contain more humus than any other soil, but the above results show that such is not the case, for the alluvial soils are richer, and even the gray loams have nearly as much as the black adobe in the first foot and are a little richer in the rest of the column.

The color of a soil, then, is no certain guide as to the relative amount of humus it contains.

Among the individual columns the richest of the alluvial group are those from Glenn and Chico, the former in the upper three feet and the latter in the entire column; there is .52 per cent in the twelfth foot of the Chico column.

The richest of the clay loam group is that from Davis, the average in the upper three feet being 1.16 per cent and an average of .755 for the entire column; the twelfth foot contains .69 per cent. The columns from Tehama, Waltons, and Willows are next in their respective percentages, Waltons being the richest in the upper three feet.

The black adobe east of Willows is the richest of the four that form the composite column, and contains an average of 1.27 per cent in the upper three feet.

Soil Columns of the San Joaquin Valley.

San Joaquin Valley, with an area of one thousand square miles, possesses many large and distinct soil types or regions, each of which is represented in our soil collection in columns of ten or twelve feet each.

Twenty-four localities in eight counties were selected from which to obtain columns of soil as nearly typical as possible of each region, and fifteen of the columns were taken to depths of ten or twelve feet, the others being limited in depth either by hardpan, coarse gravel or other obstruction which prevented the penetration of the soil auger; sometimes the water table at depths of less than ten feet produced such mushy conditions in the soil as to prevent its being removed by the auger.

Rich Alluvial Lands and Tule Marshes. The rivers of the San Joaquin Valley are usually bordered by narrow bottom lands, the Merced and Kings rivers being exceptions where they enter the valley plains. A column of eight feet depth was taken by F. E. Johnson from the lands of Kings River near Kings River post office, and is the only representative of such lands from this valley. The surface soils of other streams have, however, been examined from time to time and their humus content ascertained.

The *tule marshes* cover a very large region at the junction of the San Joaquin and Sacramento rivers and are divided up into islands by many sloughs. The soil of these islands is shallow and peaty though rich, and water appears at but a few feet below the surface. There are localities, however, where a deep soil may be found, and from one of these a column of twelve feet was obtained for us by W. W. Mackie of the United States Bureau of Soils. It was taken from a few miles northwest of Stockton, and is an excellent representative of these lands.

Black Adobe Clay Lands. A large area of black adobe land occupies an area in San Joaquin County extending from two miles north of Calaveras River south to French Camp slough and from the tules or marshes of San Joaquin River eastward toward the hills, and is timbered with oaks. The character of the soil is shown in a column twelve feet in depth taken three miles southeast of Stockton.

The region continues southward in a narrow belt along the base of the hills into Kern County, being known in Tulare County as "dry bog," because of its tendency to break up into small fragments when dry. It is here underlaid by a reddish clay loam from which it is sometimes separated by a whitish calcareous or siliceous lime and magnesian bed of varying thickness. Two columns of this black clay adobe were secured from near Porterville, one of which appears in the table of analyses.

On the west side of the valley another narrow black adobe belt reaches along the base of the hills from west of Tracy into Merced County on the south. It is represented by a column of ten feet taken three miles west of Tracy.

Reddish Clay Lands. A prominent and wide region of lands of this character occupies a large part of the eastern side of the valley; it is narrow on the north in San Joaquin, Stanislaus, Merced, and Madera counties, and on the south in Tulare and Kern, but quite wide in Fresno County. It is the southern extension of the belt of "bedrock" lands of the Sacramento Valley. It is largely characterized by a rocky hardpan of cemented gravel and grit, with thicknesses of an inch to as much as twelve inches, and even more, and occurring at depths of from two to six or eight feet below the surface; when it occurs near the surface, the

hardpan, because of its irregular bedding, gives rise to a rolling or hog-wallow feature. An excellent soil underlies the hardpan, however, and when the latter is broken up by dynamite good results in tree growth are usually obtained.

Columns of this land were obtained from a few miles east of Fresno; from the Kearney Park; from Lindsay in Tulare County; and from two miles southwest of Farmington, San Joaquin County, sent by H. Mueller.

Delta Plains of Kings and Kern Rivers. There are two tracts of this class of lowlands which are made of fine sediment brought down from the Sierra Nevada; the Coast Range on the west contributing little or nothing to these deltas, as its streams mainly flow westward to the Pacific.

The Mussel Slough region bordering Tulare Lake received its sediment from Kings, Kaweah, and Tule rivers and covers a very large area. It is timbered with oaks, and the nature of its soils are shown in columns twelve feet deep, taken respectively from near Corcoran and Armona.

The Kern River delta further south, with an area of about 290 square miles, is also timbered with oaks. It is represented in the soil collection by a column taken three miles southwest of Bakersfield. Water was reached in the seventh foot.

Gray Sandy Loams and Sandy Soils. The greater part of the San Joaquin Valley is covered with gray sandy and sandy loam soils on the east side of the valley and with gray clay loams on the west side. On the east side, the slope of the valley to the central trough is wider than on the west, and the numerous and rapidly flowing streams have brought from the Sierra much sand and gravel, which comprises from 85 to 95 per cent of the composition of the gray soils. Notwithstanding their very sandy nature these lands are usually deep and very highly productive under adequate rainfall or irrigation. Calcareous hardpans are found in some localities in irregular sheets and at various depths, but their injurious effects can be obviated in orchards by blasting; a good soil underlies them. Columns of these lands were obtained from Modesto, Stanislaus County; from three miles west of Tulare; and from a few miles north of Exeter, both in Tulare County; and from near Livingston, Merced County.

Gray Clay Loam Lands. The lands on the west side of the valley are quite level and contain more clay than those of the east side. There are but few streams on the west side, and these have their source but a short distance within the Coast Range, whose drainage is almost entirely westward. These west-side lands, therefore, must have been deposited from the waters coming from the Sierra Nevada after they had dropped

their sands and gravels on the east and become more quiet; thus permitting the fine silt and clay to settle. The soils contain from 15 to 24 per cent of clay. Columns were obtained from south of Tracy, San Joaquin County; from four miles west of Los Baños, Merced County; and from Val Verde, two miles west of Mendota, Fresno County.

Gray Alkali Lands. Some of the gray loams contain large amounts of alkali salts in small areas usually, the salts consisting of varying proportions of carbonate, sulfate and chlorid of sodium and frequently causing serious farming difficulties. Columns of soil were taken from three localities which contained very large amounts of alkali. These are as follows: from the "white ash" lands southwest of Fresno; from the old experiment station tract near Tulare; and from Miramonte, Kern County.

The "white ash" soil, so called because of its fine light, ashy and silty nature, was taken from near a vineyard in Central Colony, several miles southwest of Fresno, and is the representative of a large region lying on the north side of Kings River and reaching to within two miles of Fresno and eastward toward the foothills of the Sierra. The soils are rich and have been largely devoted to grape growing. The water table was reached at a depth of four feet, the soil assuming a white color, and, below the sixth foot, losing all traces of humus.

The Tulare column was obtained from the old experiment station tract in a spot where all vegetation had been killed by the alkali salts.

The column from Miramonte, fifteen miles west of Wasco, represents what seems to be a belt of low lands, or what was once a slough connecting Tulare Lake with those southward and in which the alkali of the lakes had accumulated to great depths. The alkali consists chiefly of the sulfates and chlorids, Glauber and common salt, and in this column it was distributed at the rate of one half of one per cent per foot, or a total approximating 233,000 pounds for the twelve feet. No vegetation other than scattering alkali weeds was seen.

Tulare Lake Bed. A large part of the bed of Tulare Lake was a few years ago quite dry, and samples of the soil to many feet depth were sent to us for examination as to their alkali content. The humus percentage of each foot was also determined.

The table below gives in a concise form the relative percentages of humus and nitrogen in the eight soil types of the San Joaquin Valley, and from it we can make comparisons more easily than from a study of the soil columns themselves. The types are placed in the order of highest to lowest composite averages of humus in the first foot, and this almost represents the succession in the combined upper three feet and the entire column respectively.

HUMUS AND HUMUS-NITROGEN IN SOILS OF THE SAN JOAQUIN VALLEY.

	Per cent humus					Per cent humus-nitrogen in soil	
	First foot	Upper 3 feet		Column, 12 feet		First foot	Upper 3 feet average
		Average per foot	Sum of per cents	Average per foot	Sum of per cents		
Tule marshes -----	14.10	16.68	50.05	6.81	81.75	.83	.88
River alluvium -----	1.29	.83	2.50	.30	3.67	.06	.04
Black clays -----	1.09	.82	2.48	.25	3.02	.06	.04
Red lands -----	.95	.76	2.28	.32	3.89	.06	.05
Delta plains -----	.81	.49	1.49	.22	2.59	.04	.03
Gray sandy loams-----	.66	.47	1.40	.25	3.05	.04	.03
Gray clay loams-----	.86	.68	2.04	.34	4.12	.06	.04
Alkali lands -----	.34	.30	.90	.12	1.47	.03	.02
Tulare Lake bed-----	.18	.14	.42	.10	1.20	.01	.01

There are large differences in the amount of humus in the several groups, as is to be expected from soils of such extremely different characters, the highest percentage being in the tule marshes and the lowest in the strong alkali lands and in the Tulare Lake bed.

The surface soils of the valley are not rich in humus as a rule, and this is well shown in these tables. Even the black clays and loams, which because of their color would be supposed to contain high percentages, were found to have but little more than one per cent, and in some instances less than that. Similarly, the alluvial and delta soils of Kings and Kern counties are very low in humus. The tule marshes in the region of Stockton are naturally rich, because of the great amount of vegetable matter, such as roots and leaves, that have accumulated in them, and we find as much as 14 per cent of humus in the first foot and 19 in the second. In but eight of the individual columns (omitting the Stockton tule) is there as much as one per cent in the surface foot, the highest being found in the reddish lands of Farmington, and the lowest, .18 per cent, in the soil of Tulare Lake bed.

In the upper three feet the amounts of humus in the alluvium, the black clays and the red lands, are nearly the same; and they are about equally rich in nitrogen; but in the column of twelve feet depth the black clays fall behind the other two, and the gray clay loams of the western side of the valley take first place in humus content.

The river alluvial lands then are richest in humus in the first foot and upper three feet, but the gray clay loams contain the highest percentage in the entire column of twelve feet. The individual soil richest in nitrogen, except the marshes, is that from Farmington, which has .14 per cent, equivalent to more than 5,000 pounds per acre foot. The average through all of the soils is low.

The alkali lands, including the Tulare Lake bed, contain very little humus and the soils are very poor in humus nitrogen, though they often have quite a percentage of nitrates. The very large amount of alkali

salts they contain evidently has so retarded or prevented the growth of surface plants as to cut off the supply of humus-forming material.

HUMUS IN THE SOILS OF THE FOOTHILLS OF THE SIERRA NEVADA.

The lower foothills of the Sierra Nevada, rising from the Sacramento and San Joaquin Valley plains to an elevation of 2,500 feet above sea level, form an important fruit-bearing region of the State. The soils are mainly derived from the slates and granites, and while they are deep in the valleys they are usually shallow on the hills, though the upturned slates permit of the deep penetration of plant roots between the layers to moisture and food.

Columns of these soils were taken from the valley lands near Palermo, Butte County; from the rolling hills of the old experiment station tract east of Jackson, Amador County; and from a bluff near Newcastle, Placer County, which afforded a deeper sampling than did the other two localities. The result of the examination of the soils from each of the localities is given in the table below, in a depth of twelve feet for the soil from Newcastle and of eight feet each for the others.

HUMUS AND HUMUS-NITROGEN IN RED SOILS OF FOOTHILLS OF SIERRA NEVADA.

	Per cent humus					Per cent humus-nitrogen in soil	
	First foot	Upper 3 feet		Column, 12 feet		First foot	Upper 3 feet
		Average per foot	Sum of per cents	Average per foot	Sum of per cents		
Palermo -----	.96	.51	1.52	.29	2.06	.06	.02
Newcastle -----	1.35	1.26	3.77	.47	5.64	.10	.05
Jackson -----	1.07	.65	1.96	.33	2.86	.05	.02

The red clay soils of Jackson and Palermo are quite similar in the amount of humus found in the first foot, but the former is richer below that depth. The clay is quite compact and close, and this seems to have prevented the development of roots to the depth permitted by the looser gravelly granitic soil of Newcastle, in which there is more humus. The general average of humus in the first foot of these three soils is 1.12 per cent; that of 31 soils of the foothills previously examined is 1.05, though it is found to be higher in the valleys farther up in the mountains, in the regions of Auburn, Grass Valley, Nevada City, and Placerville.

The nitrogen in the respective soils is below the amount it should be, except in the upper three feet of the Newcastle column, which contains an average of .10 per cent, or approximately 4,000 pounds per acre foot.

SOIL COLUMNS OF THE COAST RANGE VALLEYS.

The Coast Range of mountains reaching from the Oregon state line south to the Mexican border has but few agricultural possibilities outside of the many valleys enclosed between the mountain ridges. The country north of Mendocino County is especially rugged, and the valleys are few, but southward there are many valleys that present splendid agricultural attractions, and we have endeavored to have the soils of the largest and most important ones represented in the columns of this series. Of course, it must be understood that in each valley there are a number of soil-variations and graduations from the hills to the lower valley center, and that the column has been selected to represent the best and most extensive of these, the object being to ascertain to what depth and in what percentage the humus reaches under favorable conditions. Fifteen valleys in nine counties have their soils represented in the series of columns, and in the accompanying tables are arranged in order of occurrence from north to south.

We may conveniently follow the usual subdivision of the Coast Range counties and arrange the table into the counties *north* of the bay, embracing seven soil columns; the *bay region* itself, embracing the country east and west of the bay as far south as San Jose, represented by eight soil columns; and the counties *south* of the bay as far as Santa Barbara, represented by nine soil columns.

North of the Bay Region.

The valleys represented in this section of the Coast Range are Russian River, Santa Rosa, Los Guillocos, Sonoma, Napa, and Vaca: there are other important though much smaller ones east and west of these and in the counties farther north.

Russian River Valley. The soil columns from this valley were taken from the alluvial lands of the hop fields belonging to T. Boone Miller six miles south of Healdsburg, and from the red hills three miles southwest of Healdsburg, Sonoma County.

Santa Rosa Valley. The western part of the valley has a heavy adobe soil, which is not as largely in cultivation as is the more loamy land of the eastern and middle part. A column of twelve feet depth was taken from the creek alluvium on the Vrooman orchard east of Santa Rosa.

Los Guillocos Valley. This valley is not very wide nor long, and it opens northward into Santa Rosa Valley. Its soil is a reddish loam and is represented by a column taken a short distance southeast of Kenwood, Sonoma County.

Sonoma Valley. The valley opens southward to the bay and is largely covered by marsh lands, but the northern part is higher and

comprises better lands. A black adobe clay seems to be the prevailing soil, and a column of this was taken near the village of El Verano.

Napa Valley. The soil is chiefly loamy in nature, interspersed with some adobe belts on either side. A column of the former was obtained near Yountville, Napa County, to a depth of twelve feet.

Vaca Valley. This valley is situated among the foothills on the west side of the Sacramento Valley, into which it opens, and is noted for its early fruits. The soil is chiefly a reddish loam, as shown in the column obtained near Vacaville.

East of the Bay Region.

Alameda Plains. The bay shore rises gently eastward to the foot of the Contra Costa hills, a distance of about two miles. On this slope the soil is largely of an adobe clay nature. The city of Berkeley is situated on this slope, the University of California being at the foot of the hills. A column of the clay adobe was taken from the Economic Garden on the University Campus. Southward from Berkeley and Oakland the slope widens into a plain traversed by streams from the Coast Range bordered by wide bands of a more loamy soil, and upon it are found extensive farms and several towns. A column of the loam was taken from the land of Mrs. Sanborn south of Niles, and another from the Meek place near Hayward.

Eastward across the Contra Costa hills several narrow valleys connect the large and fertile Livermore Valley with the bay shore on the north, and representative columns of soil were taken from three of these.

Ignacio Valley. Along Walnut Creek there is a narrow belt of black clay loam soil bordered by land more adobe-like in nature which extends to the low mesa and hills. The higher land on the mesa and bordering it in the valley has a stiff and black adobe clay soil about three feet in depth and underlaid by a whitish material. The column was obtained from the place of Professor F. T. Bioletti, one mile north of Walnut Creek, Contra Costa County.

San Ramon Valley. This valley is a continuation southward of Walnut Creek Valley, but wider and with more extensive black adobe soils, a column of which was obtained in the vicinity of San Ramon post office, Contra Costa County.

Livermore Valley. The soil of the valley plain is a loam while that of the low hills of the west and south is reddish and gravelly. A column was taken to a depth of ten feet from the plain in the Santa Rita region, Alameda County.

South of the Bay Region.

Santa Clara Valley. This valley, reaching from the bay of San Francisco southward for 70 miles into San Benito County, has a variety of soils. Around the bay back from the salt marshes is a black clay adobe, a column of which was taken from the Morse Seed Farm near Santa Clara. The soil contained 4.43 per cent of humus, which is the highest we have found in any of the soils of the State except the marsh lands. South of San José the lands are more loamy in character and are represented by a column taken from near Gilroy, by F. E. Johnson. The valley west of San José has a soil more sandy in nature and more or less gravelly, on which are located extensive orchards. A column of this soil, seemingly representative of this land, was taken from the El Quito ranch, south of Saratoga.

Pajaro Valley. The soil of the valley proper is a dark loam, while along the river are adobe clays and clay loams, the latter being devoted to sugar beet culture. The valley loam is alone represented in the soil column series. It was taken from the apple-growing section on the Watsonville side of the valley. Another column of soil was taken from Watsonville heights one mile northwest of the town. At eight feet depth a mass of decomposed granite was reached. Both columns were taken by F. E. Johnson.

Salinas Valley. The lower or northern part of the valley for about 50 miles is from 8 to 12 miles wide, but to southward the valley is very narrow. Two classes of soil are represented in the series. A column of 15 feet from the sandy loam lands of the west side of the Salinas River was taken at Fort Romie near Soledad; and a column of the black adobe lands around King City, Monterey County, was kindly sent by Mr. R. L. Adams, formerly of the Spreckels Sugar Beet Company.

Arroyo Grande Valley. The soil of this narrow but important valley is of a dark and heavy clay-loam nature to the depth of twelve feet and more. Two columns were obtained by F. E. Johnson, one near the town of Arroyo Grande, the other from the farm of the Routzahn Seed Company a few miles to the westward, the only apparent difference being a darker color in the surface foot of the seed-farm soil.

Santa Maria Valley. The soil is chiefly a sandy loam of a brownish color and very deep. A column was taken by F. E. Johnson near the sugar beet fields west of the town of Santa Maria.

Lompoc Valley. Three chief classes of soils occupy the valley; adobe near the hills, sandy alluvium near Santa Ynez River, and an intermediate type of clay loam between them. The Burpee seed-farm is situated on the clay loam lands, and a column of soil was taken there to a depth of 12 feet, when water was reached.

HUMUS AND HUMUS-NITROGEN IN VALLEY LANDS OF THE COAST RANGE REGION.
North of the Bay Region.

	Per cent humus					Per cent humus-nitrogen in soil	
	First foot	Upper 3 feet		Column, 12 feet		First foot	Upper 3 feet, average per foot
		Average per foot	Sum of per cents	Average per foot	Sum of per cents		
Russian River Valley-----	1.76	1.55	4.64	1.01	12.18	.08	.06
Santa Rosa Valley-----	1.95	1.50	4.51	.92	11.10	.09	.08
Los Gualhocos Valley*-----	2.25	1.74	5.21	.92	6.45	.13	.10
Sonoma Valley -----	2.14	1.71	5.12	.84	10.05	.11	.05
Napa Valley -----	2.61	1.98	5.94	.95	11.38	.11	.08
Vaca Valley -----	1.97	1.22	3.67	.71	8.53	.13	.08

*7 feet deep.

East of Bay Region.

Alameda Plains -----	1.68	1.39	4.27	.64	9.79	.09	.08
Livermore Valley -----	.61	.67	2.02	.45	4.46	.06	.04
San Ramon Valley-----	1.23	1.19	3.59	.57	6.90	.07	.05
Ignacio Valley -----	1.42	1.34	4.02	.80	9.68	.08	.07

South of Bay Region.

Santa Clara Valley-----	3.97	2.22	6.65	1.03	11.05	.10	.07
Pajaro Valley -----	1.38	1.18	3.56	.74	6.64	.09	.06
Salinas Valley -----	1.11	.83	2.50	.55	6.66	.05	.04
Arroyo Grande Valley-----	3.14	2.15	6.47	1.33	16.60	.16	.11
Santa Maria Valley-----	1.44	1.13	3.39	.46	5.57	.11	.07
Lompoc Valley -----	2.50	1.86	5.57	1.09	13.03	.13	.09

The soils of the valleys of the Coast Range are remarkably high in their humus content when compared with the other soils of the arid region. The general average of the State is 1.25 per cent in the surface soil, while that for these coast valleys is 1.94 per cent. But especially does this difference appear when we note the many individual soils in which 1 per cent of humus is found at depths of four, five and even seven feet. In nearly all of the columns there is a decrease downward, indicating that the humification was of plant roots rather than of vegetable matter deposited from overflow as the land was being built up.

A comparison of the average amounts of humus in the soils of the three divisions shows that the lands of the valleys north and south of the bay region are richer than those on the east, both in the surface foot, the upper three feet, and in the depth of twelve feet. Santa Clara and Arroyo Grande valleys have the highest percentages in the first and the upper three feet, while Arroyo Grande and Lompoc valleys stand first as regards the entire depth of twelve feet.

It is interesting to note that Russian River Valley on the north and these three valleys on the south have averages of more than one per cent for the entire depth of twelve feet, the only instances of this among all of the soils of the State thus far examined excepting the tule marshes.

It is also to be noted that all of the valleys of this group of sixteen,

except Livermore and Salinas, have averages of more than one per cent of humus in the upper three feet, and that Santa Clara and Arroyo Grande have more than two per cent each.

The percentage of nitrogen in the first foot is highest in the valley of Arroyo Grande, .16 per cent or approximately 6,400 pounds per acre. Los Guillocos, Vaca and Lompoc valleys have .13 per cent each, Sonoma, Napa and Santa Maria, .11 per cent each, and Santa Clara has .10 per cent, while all others have less. Among the individual soils, Gilroy has .15 per cent and Berkeley .14 per cent.

In the upper three feet, Arroyo Grande and Guillocos valleys are the richest in nitrogen, the approximate amount being 12,000 pounds per acre in the three feet.

SOIL COLUMNS OF THE SOUTHERN CALIFORNIA REGION.

The region known as Southern California embraces that part of the State lying south of the Sierra Madre Mountains, and includes a number of large and fertile valleys and plains.

Saticoy Plain. The long and broad slope in Ventura County, reaching from the mountains southward to the sea shore and noted for its lima bean culture, is represented by two soil columns, one taken by J. B. Neff from near Mound Schoolhouse a few miles east of Ventura, and the other from the orange grove of Mr. N. B. Blanchard, at Santa Paula.

Santa Clara River Delta. This comprises a broad region of gray alluvial land, and contains more or less alkali salts in places. Water is usually found at a depth of 8 or 10 feet below the surface. The delta is noted for its sugar-beet culture. A column was taken near Springville by J. B. Neff to a depth of 8 feet, where water was reached.

Pleasant Valley Hill Slope. This column was taken from the sandy slope of the hills north of the Southern Pacific Railroad station at Camarillo, on the property of the Citrus Farms Company.

San Fernando Valley. The valley of San Fernando lies north of Los Angeles and includes about 200 square miles. Much of the valley on the east is covered by débris of cobblestones, gravel sand washed from the canyons on the northeast, but the rest of the valley has sandy and sandy loam soils, with some heavier clays on the south.

Two columns were obtained by F. E. Johnson: one from the sandy lands about one half mile north of Fernando, representing the "granitic wash land" at the foot of the hills; the other from lowland near the old Mission two miles west of Fernando.

San Gabriel Valley. This valley lies east of Los Angeles and reaches from the mountains southward to the alluvial plains. It is watered by the San Gabriel River and bordered on the east by the Puente Hills, and San Antonio débris cone. Its soil is a sandy loam. A column of

soil was taken by F. E. Johnson from the neighborhood of Covina and "represents an average of all of the different soil types." Another column was taken by Johnson from near Monrovia, and represents the heavier type of soil, the greater part of which is sandy and gravelly wash from the hills.

San Bernardino Valley. The eastern portion of the valley of Southern California, known as the San Bernardino Valley, is separated from the western by a range of low hills and by the débris cone of the San Antonio Creek, which issues from its valley just above Pomona and supplies most of the water to Chino Creek, which empties into the Santa Ana River. In the past, from time to time portions of the San Antonio flow has been diverted into the San Gabriel.

The valley covers a large area and comprises a large variety of soil types, a few of which are represented by soil columns. The valley slopes toward the south to the Rineon Basin and Santa Ana River, and is bordered by a rim of mesa on the north, east, and south.

The Valley Plains. The soils are chiefly of a sandy nature, of excellent depth and good fertility. The lowlands are sometimes highly charged with alkali that has been brought in by drainage from the higher valley. Several types of soil from the plains are represented in the columns.

Sandy loam soils of the central part of the valley are shown in a column from the former University of California Experiment Station tract, three miles southwest of Ontario, taken by J. W. Mills.

Highly sandy soils, apparently accumulated by wind storms blowing in from the mountain passes on the north, lie in the central part of the valley and are extensively planted in grapevines, the roots of which penetrate downward for very many feet. A column of this type of soil was secured at Guasti from the land of the Italian Vineyard Company.

Alluvial plains of the Santa Ana River, known as the Victoria Tract, a few miles east of San Bernardino.

The soils of the valley plain are all quite sandy and contain but small amounts of humus and of nitrogen. The tendency to crust over and to form a sandy hardpan or plowsole near the surface is quite usual with these soils. A succession of good green-manure crops grown, turned under deeply, and allowed to humify properly would add much to the value and fertility of these lands.

Low Lands. Near the border of Chino Creek there are low-lying lands forming a wide border of "moist lands" which do not need irrigation. Ten acres of these near Chino formerly formed a part of the Experiment Station of Southern California. A column from this was

taken by F. E. Johnson. Another column was taken near Pomona from a marsh spot known as a "cienega." This is a "limited area showing growth of water-loving plants, appearing sporadically in otherwise arid surroundings—usually hillsides or valley margins—and occasionally giving rise to flowing springs." (Rept. Cal. Expt. Sta., 1892–1894, page 185.)

Mesa Lands. The mesa lands that border the valley are largely of a reddish loam type, interspersed on the north side by deposits of sand and gravel from the hillsides.

The red mesa extends eastward up the Gorgonio Pass to its summit at Banning, where it forms quite a high plateau above Timoteo canyon.

A column of the sandy mesa of the north side was taken in the western part of Highlands to a depth of twelve feet, in which the sandy soil continued to the bottom.

A column representing the red clay mesa was taken near Redlands by F. E. Johnson. The upper five feet were of reddish, sandy loam nature, below which there is a change to a sandy clay and finally to a gritty stratum.

A column from Riverside was taken from Arlington Heights orchard lands on the south, and we were able to reach a depth of eighteen feet with comparative ease.

Another mesa soil column was taken by F. E. Johnson from nearly one mile south of the town of Corona, and is a good representative of the orchard land of that vicinity. A depth of twelve feet was reached with difficulty because of the presence of much gravel.

Los Angeles Alluvial Plain. The three rivers, Los Angeles, San Gabriel and Santa Ana, have each brought down from the San Bernardino Mountains large quantities of silt, sand and clay, and formed a large body or region of alluvial lands, known as the Los Angeles Alluvial Plains. Each river preserves its own course through these plains, and has built up its own alluvial plain with its own material independently of the others. We thus find that the soils of the San Gabriel are of a more sandy nature than those of the Santa Ana, probably because of the greater velocity of the river current over a shorter distance. The Santa Ana leaves the mountains east of San Bernardino and flows by a circuitous route along the southern side of the valley and thus has left most of its coarse material behind and deposited chiefly clays and silts in the alluvial plain.

The San Gabriel Plain is represented by three columns. One was taken from the place of Doctor Twombly, south of Fullerton, to a depth of ten feet; another from the place of J. B. Neff, near Anaheim; while the third column was taken a mile south of Compton.

The Santa Ana Alluvial Plain is represented by two columns taken by F. E. Johnson. One of these from two miles south of Santa Ana, to represent a considerable area of heavy black adobe. The other from Irvine, six miles southeast of Santa Ana, represents a lighter clay loam soil. Both of these columns are from the south side of Santa Ana River.

INTERIOR VALLEYS.

The immediate coast line is bordered by a wide mesa which extends south to the state line, interrupted by characteristic deep and narrow valleys or occasional streams. The valley of San Diego River is wide and affords much land for culture purposes. The mesa reaches eastward in considerable width to the foot of the higher rolling hills, which rise still higher into the San Jacinto Mountains. Numerous valleys small and large lie among these hills, whose soils are rich and productive.

Fallbrook Mesa. . The hills or mesa are for the most part somewhat rolling and capable of cultivation whenever the soil is of sufficient depth and extent. Fallbrook affords an example of these cultivable hills, and a column of the soil was taken from the hillside vineyard of Loma Ranch, south of the town. The red clay loam soil was of varying thickness and underlaid by a mass of disintegrated granite.

Perris Valley lies southeast of Riverside at the western foot of the San Jacinto Mountains. It is about 10 miles long and 6 miles wide, and has a variety of soils as described by Professor Hilgard in the annual report of this experiment station for 1894-95. The heavier soil from the center of the valley about a mile east of the town of Perris was selected and a column taken by F. E. Johnson.

The Valley of Escondido is large and productive, lying at the edge of the mountain. Its soil is a loam. A column was taken to a depth of twelve feet by F. E. Johnson in the vineyard of C. C. Katzenburger on the north side of the valley.

El Cajon Valley lies among the high mountains 29 miles east of San Diego and has an area of 6 by 4 miles. The land is a reddish sandy loam and is very productive. A column twelve feet in depth was taken from near the crossroads by F. E. Johnson.

HUMUS AND HUMUS-NITROGEN IN SOILS OF SOUTHERN CALIFORNIA.

	Per cent humus					Per cent humus-nitrogen in soil	
	First foot	Upper 3 feet		Column, 12 feet		First foot, per cent	Upper 3 feet, per cent
		Average per foot	Sum of per cents	Average per foot	Sum of per cents		
Saticoy Plain -----	1.23	.95	2.86	.52	6.90	.06	.05
Santa Clara Delta-----	.96	.65	1.96	.34	2.84	.07	.04
Fernando Valley -----	.90	.71	2.12	.43	5.23	.04	.03
Camarillo hillside -----	.84	.65	1.96	.30	3.66	.05	.02
San Bernardino plains-----	.43	.41	1.22	.16	1.95	.02	.02
San Bernardino mesa-----	.67	.44	1.33	.28	2.75	.04	.03
San Bernardino lowlands-----	4.28	2.59	7.79	1.20	11.63	.18	.10
Alluvial plains -----	1.16	.84	2.65	.44	5.26	.07	.05
Perris Valley -----	.35	.59	1.77	.30	3.60	.05	.03
Fallbrook -----	.55	.37	1.12	.15	1.78	.03	.02
Escondido Valley -----	.47	.29	.89	.13	1.56	.03	.02
El Cajon Valley -----	.93	.50	1.50	.18	2.10	.05	.02

The nitrogen percentages are nearly all too low and indicate the great need of good green-manuring for a number of years to build up the upper three feet of soil into a high fertility. This is needed more than phosphate fertilization.

There are but six of the twenty-five soils whose surface foot contains more than one per cent of humus; there are but five others that have more than .75 per cent, and there are five whose humus falls even below .50 per cent.

The lands represented by these columns from Southern California are under such continuous cultivation that the surface foot is hardly a proper unit of comparison; a depth of three feet would be more nearly correct, for in that is usually found the mass of feeding roots, and no disturbing irregular conditions exist. The general average of the total amount in the three upper feet (sum of per cents) of the columns (omitting that of the Pomona Arroyo), is 1.98, or an average of .66 per cent per foot.

The Santa Ana adobe and Chino moist land have each above 4.50 per cent in the upper 3 feet and Mound has 3.11 per cent, but all others fall below the latter. Six of the columns have more than two per cent each, while on the other hand three have each a sum of less than one per cent in the three feet or an average of but .25 per cent per foot.

The humus in these soils is with a few exceptions not especially rich in nitrogen, and, as a consequence, the soil is but meagerly supplied with that element.

SOIL COLUMNS OF THE NORTHEASTERN LAVA-BED REGION.

The lava-bed region, comprising a large portion of the northeastern part of the State, reaches north from the Sierra Nevada Mountains into Oregon, and is a region of lava-bed plateaus and hills interspersed with occasional valleys that are capable of cultivation to a large extent in grain and alfalfa.

Honey Lake Valley. This valley with its large lake lies between the foot of the Sierra and the lava hills on the north, and has an elevation of about 4,000 feet above sea level. It is divided into the Honey Lake Valley proper and the East Side Valley, which extends from the Lake eastward into the desert region.

Honey Lake occupies the lower part of the valley and is bordered on all sides by lands which are being brought under cultivation in grain and alfalfa, except on the east, which is of a more sandy and alkali nature. A column of soil was taken to a depth of ten feet from near Standish on the north side of the valley, humus being found only in the upper five feet; a large and luxuriant growth of alfalfa covered the adjoining fields.

Another column of soil taken by Professor G. W. Shaw from a strong alkali tract bordering the lake on the east side near Amedee, contained but little humus.

East Honey Lake Valley. This desert-like region comprises that portion of Honey Lake Valley in Lassen County that reaches eastward from the lake into Nevada at an elevation of about 100 feet more than the lands around the lake, and lies between hills of lava débris. The width is about 15 miles, but increases to much more toward the state line. The soil of the plain is for the most part quite free from alkali salts, which only appear here and there on the surface; but toward the state line at lower levels the alkali is more abundant. On the north side of this plain the soil is quite level and sandy, with a reddish sandy subsoil.

A wide belt of alluvial land borders Skedaddle Creek with a depth of three or four feet near the creek. Beneath this there is, as shown in a well on the place of A. L. Spoon at Stacy Station, two feet of sand, twenty feet of a calcareous clay, underlaid in turn by blue sand and clay. A column of soil was taken for examination from this place to a depth of twelve feet. Its upper foot contained .64 per cent of humus, the second foot 1.26 per cent and below this the humus percentage decreased to .20 per cent in the twelfth foot.

It is interesting to note here that a well on the place of Mr. Caudle, north of Stacy, exposed three feet of a reddish soil, three feet of sand, seven feet of boulders and fifteen feet of white calcareous clay; below

this appeared blue clay to a depth of 320 feet from the surface, water being reached at that depth.

In the center of the valley the surface of the land is in low ridges, the sandy soil being blown into hillocks; the soil is underlaid by a very compact gray silty soil to ten feet; then beneath that is ten feet of a fine sand, followed by ten feet of a coarse sand in which water is struck in wells. Beneath this lies a blue clay of fifty feet or more thickness. A column of soil was taken in this land to twelve feet depth from near the place of Dr. B. B. Bolton four miles north of Calneva. In this the humus occurred in each foot of the column, but in very small amounts. On the south of the Western Pacific Railroad at Calneva to the mountains the soil is coarsely sandy.

Madeline Plains. Passing north from Honey Lake Valley across hills covered with beds of lava we come to the Madeline Plains, which occupy a large and almost level basin (probably once an inland lake) at an elevation of 5,200 feet above sea level. Its area is approximately 150 square miles, very irregular in outline, and bordered on all sides by lava hills. Its soil is a dark and very compact clay underlaid at three or more feet by a light colored marl of a hardpan nature and upwards of 75 feet in thickness, as shown in well borings. A column of this soil four feet in depth was obtained from the plain to westward of the place of W. C. Brockman. Previous analyses of other samples show fair amounts of phosphoric acid. Grass and grain are said to do well on this plain. The surface foot was found to contain .52 per cent of humus, and the second foot .60 per cent, but below this the clay was almost free from it. The soil contains about .04 per cent of humus nitrogen.

Pit River Valley. Pit River, with its source at the foot of the Warner range of mountains, passes through a number of valleys as it flows westward into the Sacramento River. The town of Alturas is located in one of these valleys at the junction of the two forks of the river. The soil of the valley is chiefly meadowland, with water at a few feet and partly grown in tules, but affording large alfalfa tracts. A column of six feet was taken from an alfalfa field near the town. The valley is bordered by lava-bed mesas and hills. Goose Lake Valley to northward and reaching into Oregon has a similar meadowland soil reaching from the lake eastward to the foot of the mountains, where the disintegrated débris afford some higher land on which orchards are planted.

Klamath Lake Marshes. A column from the tule marshes of Klamath Lake, Butte Valley, Siskiyou County, was obtained for us by Mr. L. S. Robinson for examination.

Surprise Valley. Eastward from Alturas, the Warner range of mountains separates the Pit River Valley from Surprise Valley with its three large lakes. The land of this valley on the east is strongly charged with alkali salts, but on the west the broad slope from the mountains to the lake presents excellent agricultural possibilities, the production of alfalfa seed being quite a prominent industry. A column of soil ten feet deep (to water) was obtained from the valley two miles south of Cedarville, and another column of four feet from the meadow-land that forms a broad border to the lake and in which water was struck at four feet.

HUMUS AND HUMUS-NITROGEN IN SOILS OF THE LAVA-BED REGION.

	Per cent humus					Per cent humus-nitrogen in soil	
	First foot	Upper 3 feet		Column, 12 feet		First foot	Upper 3 feet
		Average per foot	Sum of per cents	Average per foot	Sum of per cents		
Honey Lake Valley -----	.54	.45	1.35	.23	2.73	.03	.02
Pit River Valley -----	3.05	1.84	5.51	1.20	7.23	.06	.06
Surprise Valley -----	4.29	2.25	6.75	1.10	10.98	.05	.04
Surprise Valley meadows-----	2.71	1.89	5.67			.09	.09
Klamath marsh -----	3.75	3.32	9.97	1.81	14.52	.34	.29

The soils from the Honey Lake Valley contain very little humus even in the surface foot, but it is found throughout the entire column except at Standish, and it is very poor in nitrogen. The humus is apparently derived from the débris and roots of the sagebrush and alkali weeds that grow on the plain.

With an abundant water supply and the turning under and humification of some good legume crop there is no reason why the lands of East Honey Lake Valley, at their elevation of 4,000 feet above sea level, should not produce crops suitable to that altitude as well as the lands of Imperial Valley which are below sea level, though climatic conditions naturally would control the kind of crops grown.

The column taken from Standish on the north side of the lake and from an alfalfa field is surprisingly low in humus below the surface foot. The underlying whitish limy loam seems to have restricted the development of plant roots to the upper four feet. The humus is also poor in nitrogen and was probably derived from the meager roots of sage and alkali weeds. A soil previously taken from the Susanville Meadows had only .33 per cent of humus, and another from two miles west of Amedee had but .29 per cent. The Pit River Valley clay soil is under cultivation in alfalfa, and the amount of humus is large, though very poor in nitrogen. On the other hand, the Klamath column is from tule marsh lands, containing a larger proportion of decaying vegetable matter, and consequently is quite rich in humus in each of the

upper four feet. The humus is especially rich in nitrogen, and, as a consequence, the soil is also enormously rich in it through its upper four feet. The fifth and sixth feet are largely made up of diatomaceous earth in which the humus has suddenly diminished to less than one per cent, while beneath this there is but a trace of humus.

The surface soil of the Cedarville loam is surpassed in its percentage of humus (4.29 per cent) by only the black clay of Santa Clara and the marsh lands among all of the soils of the State thus far examined, and it ranks as fifth with regard to the amount in the three upper feet. The percentage throughout the entire column of ten feet is quite high. This high humus content may be due to the alfalfa crops that have been produced for seed on this soil for a number of years past, as a soil from another locality near Cedarville examined ten years ago contained but 1.56 per cent in the surface foot. The humus is, however, remarkably weak in nitrogen (1.14 per cent) if such was its origin.

The meadow soil lying at a lower level is very similar to that of Alturas in its humus content.

SOIL COLUMNS OF THE "DESERT" PLAINS.

The term "desert" is here applied to the extent of country with scant rainfall and having a vegetation of sagebrush and largely devoid of grasses; a country whose soils are usually rich in the mineral elements of plant food and which are remarkable for their fertility when properly cultivated and abundant irrigation water is used. The reason for this fertility lies partly in the fact that the humus, though small in amount, is with its nitrogen well distributed throughout a depth of twelve feet and more, in a soil whose sandy or silty texture permits deep rooting of plants.

Some of the valleys have with irrigation been brought under cultivation and settlement, and from these a few soil columns were secured.

Imperial Valley. This newly settled part of the State, the bed of Salton basin, which on drying up became a desert until reclaimed by irrigation, largely lies below the level of the sea. Its soils, derived from the sediment of the Colorado River, have a peculiar light pinkish tint, and are made up of alternating strata of silt and a very plastic impervious clay of varying thickness. When this clay forms the surface soil, the difficulties of cultivation and irrigation are very great, but when the clay lies at a depth of several feet below the surface of silty soil, the reverse is true. This peculiar type of land is represented in the series by two columns of soil, one from the vicinity of Imperial and the other from near El Centro; these and that from Coachella were taken by F. E. Johnson.

Coachella Valley. A column was obtained from the vicinity of

Coachella and represents the higher and more sandy lands that bordered the old Salton Lake of the Imperial country.

Mojave River Mesa. This mesa or plain is formed by accumulation of granitic débris from the Sierra Madre Mountains on the south and reaches far out toward Barstow, San Bernardino County. This débris is coarse and quite compact, and in the neighborhood of Victorville is said to have a thickness of 35 feet or more. It is here overlaid by about three feet of a gray sandy soil, also quite compact and supporting a sparse vegetation of weeds. A column of eleven feet was obtained three miles west of Victorville. The soil was found to contain but .13 per cent of humus in the surface foot, .14 per cent in the second, .10 per cent in the third, and .08 per cent in the coarse sand of the fourth foot. There were but traces of nitrogen in the humus.

Owens River Valley. The agricultural lands of this valley lie chiefly on the western side of Owens River and are formed from the débris of the adjoining Sierra Nevada. A column of soil was secured through the kindness of Mr. W. K. Winterhalter of San Francisco.

HUMUS AND HUMUS-NITROGEN IN SOILS OF THE "DESERT" PLAINS.

	Per cent humus					Per cent humus-nitrogen in soil	
	First foot	Upper 3 feet		Column, 12 feet		First foot	Upper 3 feet, average
		Average per foot	Sum of per cents	Average per foot	Sum of per cents		
Imperial Valley -----	.28	.24	.72	.22	2.68	.02	.01
Coachella Valley -----	.32	.23	.68	.15	1.86	.01	.01
Mojave River Plains-----	.13	.12	.37	.04	.45	trace	trace
Owens Valley -----	.31	.24	.73	.13	1.56	.01	.01

It was to be anticipated that the soils of what are known as the desert plains of the eastern and southeastern part of the State would be very poor in humus because of their very sandy nature together with small rainfall, extreme summer heat and scant vegetation, but it was a surprise to find that humus occurred at depths of twelve or more feet below the surface. The soil poorest in humus is that from the mesa plain just west of Victorville, in which plant roots were found to a depth of three feet only, the underlying material being too compact for root penetration. It, however, supported a growth of yucca and desert weeds, and on the same mesa with presumably the same soil though deeper, near Hesperia there are a few orchards. A glance at the table shows that there is nearly the same percentage of humus in the first foot of each of the columns and very little difference in the total amount in the upper three feet of the columns.

The very unequal distribution in the El Centro column is somewhat surprising, for it might readily be supposed that the small amount in

the surface foot would indicate that there was scarcely any in the lower depths; whereas we find higher percentages in the fourth, fifth, eighth, and tenth foot respectively than in either of the upper three feet. It is interesting to note that there is more in the lower half of the column than in the upper. The humus of these columns is not quite as rich in nitrogen as that of the soils from other parts of the State, and that of the Bishop column is extremely low. The nitrogen of the soil is not more than .01 per cent or about 400 pounds per acre foot.

Individual Soil Columns Having the Highest Humus Content.

In looking over the 109 columns of soil taken from the various agricultural regions of the State we find that eighteen have each more than two per cent of humus in the surface foot, and thirty-two others have more than one per cent, the remaining fifty-nine having less than that. We also find that nine of the columns have each an average of more than two per cent of humus in each of the upper three feet, and twenty-five others have an average of more than one per cent, all others falling below the one per cent. In the distribution of the humus through the entire twelve feet of the columns there are ten which give an average of more than one per cent for each foot, and twenty-five others whose average is above one half of one per cent.

In the following table we have placed the names of the twenty localities which have as much as 1.95 per cent in the surface foot, and the twenty which rank highest in averages of the upper three feet and in the entire column of ten or twelve feet.

SOIL COLUMNS HAVING THE HIGHEST HUMUS PERCENTAGES.

In first foot	Average of upper 3 feet	Average of entire column of 10 or 12 feet			
Stockton tule -----	14.10	Stockton tule -----	16.68	Stockton tule -----	6.81
Pomona cienequa ---	6.23	Pomona cienequa ---	3.67	Arroyo Grande -----	1.39
Santa Clara adobe--	4.43	Santa Clara adobe-	3.63	Santa Clara (10 feet)	1.33
Cedarville -----	4.29	Klamath marsh ---	3.32	Pomona cienequa ---	1.28
Arroyo Grande Seed Farm -----	3.78	Cedarville -----	2.25	Arroyo Grande Seed Farm -----	1.27
Klamath marsh ---	3.75	Gilroy -----	2.23	Gilroy -----	1.14
Alturas -----	3.05	Arroyo Grande Seed	2.16	Cedarville (10 feet)-	1.10
Gilroy -----	2.76	Farm -----	2.01	Lompoc Seed Farm-	1.09
Cedarville meadows	2.71	Berkeley adobe -----	2.01	Berkeley -----	1.04
Yountville -----	2.64	Yountville -----	1.98	Russian River -----	1.01
Lompoc Seed Farm-	2.50	Cedarville Meadows	1.89	Yountville -----	.95
Arroyo Grande -----	2.50	Lompoc Seed Farm-	1.86	Santa Rosa -----	.92
Santa Ana adobe---	2.42	Alturas -----	1.84	El Verano (10 feet)-	.84
Chino moist land--	2.31	Kenwood -----	1.74	Walnut Creek -----	.80
Kenwood -----	2.25	El Verano adobe---	1.71	Hayward -----	.77
El Verano adobe--	2.14	Farmington -----	1.65	Davis University	
Berkeley adobe -----	2.13	Santa Ana adobe--	1.63	Farm -----	.75
Farmington -----	2.04	Russian River -----	1.55	Watsonville -----	.74
Vacaville -----	1.97	Chino -----	1.52	Chico -----	.73
Santa Rosa -----	1.95	Glenn -----	1.51	Vacaville -----	.71
				Glenn -----	.69

Composite Columns of Agricultural Regions.

In the following table are given the averages of each of the agricultural regions, embracing all of the 109 columns representing the State at large, taken from thirty-seven counties. The tule marshes of Stockton, Pomona, and Klamath are placed in a column by themselves. In some of the individual columns that form the composite for each region either a depth of twelve feet was not secured or the humus itself was not found to that depth.

COMPOSITE AVERAGES OF AGRICULTURAL REGIONS (PER CENTS)..

	Sacra- mento Valley	San Joaquin Valley	Coast Range valleys	Southern Califor- nia	Sierra Nevada foothills	N. E. lava-beds valleys	"Desert" plains	Tule marshes
	18 columns	23 columns	24 columns	25 columns	3 columns	8 columns	5 columns	3 columns
1 foot -----	1.04	.80	1.94	.88	1.12	1.55	.26	8.04
2 feet -----	.75	.51	1.47	.65	.71	.92	.19	8.59
3 feet -----	.58	.37	1.13	.45	.57	.48	.17	7.05
4 feet -----	.45	.25	.93	.37	.39	.40	.25	5.52
5 feet -----	.36	.23	.77	.31	.18	.21	.18	2.65
6 feet -----	.32	.17	.67	.27	.14	.18	.13	1.45
7 feet -----	.23	.14	.59	.25	.18	.13	.13	.78
8 feet -----	.19	.10	.49	.19	.10	.12	.14	1.64
9 feet -----	.18	.18	.41	.16	-----	.11	.12	.68
10 feet -----	.17	.06	.39	.16	-----	.09	.13	.30
11 feet -----	.16	.06	.27	.13	-----	.03	.15	.21
12 feet -----	.15	.04	.32	.11	-----	.03	.13	.29

In 12 Feet.

Sum of per cents---	4.58	2.91	9.38	3.93	3.93	4.25	1.96	37.20
Nitrogen in humus--	5.45	6.53	5.15	5.54	5.64	3.69	4.69	5.63
Nitrogen in soil---	.03	.02	.04	.02	.03	.03	.01	.20

In Upper 3 Feet; Range of Most Annual Plant Roots.

Sum of per cents---	2.37	1.68	4.54	1.98	2.40	2.95	.62	24.68
Nitrogen in humus--	5.79	6.27	5.13	5.74	5.40	3.79	4.97	5.75
Nitrogen in soil---	.04	.04	.07	.03	.05	.05	.01	.44

In Surface Foot.

Nitrogen in humus--	5.68	6.08	5.43	6.50	5.93	3.53	5.03	6.35
Nitrogen in soil---	.05	.05	.10	.05	.07	.05	.02	.47

On glancing at the table, attention is first called to the depth of twelve feet to which humus reaches in all of the columns except that of the Sierra Nevada foothills, the lava-bed meadows and the tule marshes where, because of the underlying country rock on the one hand and of water on the other, the depths are limited to eight, ten and seven feet respectively. In some of the columns the amount of humus is so high in the twelfth foot, especially in that of the valleys of the Coast Range, as to leave no doubt of its being found at a greater depth had the examination been made. In fact, the column of Fort Romie was

carried through fifteen feet, and .41 per cent of humus with 6.83 per cent of nitrogen was found in the lowest foot.

The next point of interest is the small amount of humus in the first foot of each of the columns excepting those of the meadow lands and the tule marshes. This is especially noticeable in the composite of the San Joaquin Valley and in that of the "Desert" plains. The general average for all of the columns excluding the marshes is 1.16 per cent.

Another point of special interest is the gradual diminution of humus percentage downward in each of the composite columns, with an occasional slight increase, as is seen in the eleventh foot of the Sacramento Valley and the twelfth foot of the Coast Range valleys. This decrease indicates smaller amounts of humus-forming vegetable material, presumably the roots of plants, in each successive foot downwards, the main mass of the root systems being in the upper three or four feet.

Average of Three Upper Feet. A depth of one foot does not in reality represent a soil in this State which is at least three feet deep, and it would not be correct or fair to the cultural possibilities of the land to draw conclusions from the humus of the first foot alone. It is very true that its presence to the extent of several per cent near the surface is of special importance in maintaining proper physical textural conditions for aeration, avoidance of crusts and easy penetration of water, but it is of as great importance that there should be several per cent of humus in each of the upper several feet, for in arid regions it is below the first foot and away from hot and dry top soil that the feeding roots of plants prefer to carry on their activities, and it is in the upper three feet that the main mass of fine feeding roots is usually located, and where they must secure the needed plant food supplied by the humus. This not only protects the roots, but gives to them a far greater feeding area, which is enlarged with the extension of the humus downward. The summations for three feet are given at the foot of the table.

Sacramento Valley. The Sacramento Valley represented in the above table by a composite column of eighteen individual columns is not only richer than the San Joaquin Valley in the first foot in humus, but in every foot of the entire column to a depth of twelve feet. One half of the total amount is held in the upper three feet. Its first foot contains a little less than that of the Southern California column, but in the upper three feet and in the entire column there is more. The percentage in the first foot is too small and clearly shows the need of its being increased by a system of growing and turning under of green crops. With this to encourage the growth of the young grain and trees the lower portion of the column will afford humus nitrogen and other plant food for the roots that find their way downward to twelve or more feet, as was the case with wheat and barley roots on the University farm at

Davis. In the latter soil the humus of the first foot was only .85 per cent and that of the second foot 1.49 per cent; the ordinary yield had been but from 12 to 14 bushels of wheat per acre before the University bought the property. By proper method of treatment and without irrigation or fertilization the agronomist in charge, Prof. G. W. Shaw, secured a yield of 40.4 bushels of wheat per acre as an average of three years, during which time the average for the State was but 14.5 bushels. (Bulletin No. 211.)

The humus-nitrogen content of the upper three feet of the Sacramento composite column is 5.79 per cent of the humus and .04 of the soil. This is approximately 1,600 pounds of nitrogen per acre for each foot in depth.

San Joaquin Valley. The composite of 23 columns from the San Joaquin Valley show humus percentages much below those of other regions both in the surface foot (.80 per cent) and in each foot of the entire column. The sum of 2.91 per cent, if contained in the upper foot of the three feet would be a fair amount, though much below that of other regions. The low percentages may be due in part to the presence of alkali salts in some of the soils examined, also to a more arid climate of far less rainfall than in other regions, and to a less luxuriant vegetation upon the decay of whose roots the amount of humus is dependent.

Although this humus percentage is so low in the upper part of the soil, yet a proper system of deep plowing to break up any tendency to form a plowsole and to make the soil loose and of good texture for a downward development of the crop roots, which may thus secure the benefits of the humus, would tend to greatly increase the grain yields of the valley. This was shown in the experiments of Prof. G. W. Shaw at Ceres and Tulare,* where, during a period of three years by this method the average yield of wheat was 35 and 33 bushels respectively, while the average wheat yield for the State was 14.5 bushels per acre. No irrigation or fertilization was used in his experiments.

The humus-nitrogen of the upper three feet of the composite column is 6.27 per cent of the humus, which is higher than in any of the other composite columns in the table. In the soil itself, however, there is but an average of .04 per cent or 1,600 pounds per acre foot.

Sierra Nevada Foothills. The composite of three columns from the Sierra Nevada Foothills shows more humus in the first foot than in that of the Sacramento Valley or Southern California. That of the second foot is, however, somewhat less and there is a greater decrease in the lower part of the column, the sum being but 3.39 per cent in the eight feet. More than one half of the humus is held in the upper three feet.

*Bulletin No. 211.

The humus-nitrogen in the upper three feet of the composite column is 5.40 per cent of the humus or .05 per cent in each foot of the soil, and is equivalent to 2,000 pounds for each acre foot in the three feet.

Coast Range Valleys. The composite column of the 24 soils of the valleys of the Coast Range shows a general average of nearly two per cent of humus in the surface foot, and thus is far above each of the other columns, except the marshes and meadow lands. Not only that, but it is the only column of the uplands which has more than one per cent in the soils immediately below the first foot. The percentage of humus in each of the succeeding feet throughout the twelve feet is also higher than in any other of the composite columns; the twelfth foot has nearly one half of one per cent and the sum of the entire column is 9.38 per cent. The humus is not as rich in nitrogen as that of the San Joaquin or Southern California, and the amount of organic nitrogen in the soil is below the .05 per cent regarded as necessary for fertility.

Southern California. The soils of the valleys of Southern California represented by the composite of twenty-five columns have about the same humus content in the first foot, and in the upper three feet, as was found in similar parts of the columns from the Sacramento Valley and the Foothills; but is far behind that of the Coast Range valleys. The humus is well distributed downward to twelve feet, and, as with the Sacramento Valley soils, affords an excellent and large feeding area for plant roots. Every encouragement should be given crops to take advantage of this by sending their roots deep into this fertile soil mass. The upper three feet contain a little less than one half of the total humus.

The humus of the first foot is too low for the maintenance of good physical condition and careful attention should, as a rule, be given to the turning under of green crops and the humification of the same.

The humus in the upper three feet contains 5.74 per cent of nitrogen, but there is only .03 per cent of organic nitrogen in the soil: this is equivalent to about 1,200 pounds per acre foot, which, under the influence of bacteria, gradually becomes available for plants.

“Desert” Plains. The “Desert” lands represented by a composite of five columns from the valleys of Imperial, Coachella, Owens River and Mojave River are very low in humus in their upper several feet, as is to be expected from the meagerness of the natural humus-forming vegetation. One half of the humus is held in the upper five feet instead of in three as is the case with other regions. The presence of so much humus in the twelfth foot is a matter of some surprise, for the lands seem usually quite deficient in natural moisture other than hygroscopic for hundreds of feet in depth. The amount of humus in the twelfth foot is one half that of the first foot.

The humus of the upper three feet contains but 4.97 per cent of nitro-

gen, and there is but .01 per cent of organic nitrogen in the soil: this is equivalent to about four hundred pounds per acre foot, which is very low.

Lava-bed Valleys. The valley lands of the lava-bed region of the northeastern part of the State have in the composite of eight columns a high percentage of humus, not only in the first foot but in the second. This is natural, as the soils are moist from underlying water and there is a strong vegetation whose roots penetrate deeply. The total sum of humus percentages in the 12 feet is 4.25 per cent, the upper three feet holding more than one half of it. The humus is poorer in nitrogen than in any of the regions except the desert, the average in the upper three feet being 3.79 per cent, or .05 per cent in the soil.

Tule Marshes. The tule marshes near Stockton and Klamath, and the Pomona ciénega have extremely high humus percentages in each of the four upper feet, and the humus is also quite high through the column of eight feet, all derived from the large amount of decaying tule roots. The humus nitrogen of the upper three feet is, however, only 5.75 per cent in the humus or .44 per cent in the soil; the latter is much higher than found in any of the columns.

Nitrogen in the Humus.

Nearly one thousand determinations of nitrogen were made in this investigation, and of these there were but 64 where the humus was found to contain more than 10 per cent of nitrogen; fourteen of these had from 15 to 20 per cent and but five had more than 20 per cent. The latter percentage was found in the eighth foot of the Berkeley adobe, the fourth foot of Watsonville Heights loam, the sixth foot of the Kenwood loam, the sixth foot of Santa Paula loam, and the fifth foot of the Fullerton loam.

The general average for all of the soils, including the marsh lands, is 5.92 per cent for the first foot, 5.60 per cent for the upper three feet and 5.57 per cent for the entire depth of twelve feet.

The humus of the surface foot of the composite of Southern California soils is richer in nitrogen than that of any of the other regions though nearly equaled by that of the tule marshes. That of the lava-bed valleys is poorer in nitrogen than any others.

The humus of the upper three feet of the composite column of the San Joaquin Valley is much the richest in nitrogen, and that of the lava-beds again the poorest. Four of the eight columns fall below the general average for the State. The same is true for the averages of the twelve foot columns.

The differences in the percentages of nitrogen in the humus of the upper three feet and of the total columns are not very great, except in the valleys of the Coast Range, where it is considerably smaller; and in

the lava beds and "Desert" plains where there is a very material falling-off.

Organic Nitrogen in the Soil.

It is well to remark here that .10 per cent of nitrogen in the upper foot of a humid soil is regarded as an ample supply for fertility, while in the arid region with its deeper soil, deeper humus and deeper root penetration, one half that amount, or .05 per cent in each of the three upper feet is considered sufficient for many years, because the roots are in a larger feeding area than in the humid region, and bacterial activity is greater and deeper. This percentage would mean 2,000 pounds of nitrogen per acre in each foot.

The marsh or tule soils of the State have very high amounts of nitrogen, as shown in the Stockton tule .83 per cent, Klamath tule .34 per cent and the Pomona ciénega .25 per cent, and is probably due to their wet, soggy condition and lack of aeration. This nitrogen is, however, less available than that of the dry uplands, hence a comparison can not be made. The surface soils that are richest in nitrogen are, the two soils from the Arroyo Grande Valley, including the Routzahn Seed Farm with their .16 per cent of nitrogen each, Gilroy with .15 per cent, Berkeley and Farmington each with .14 per cent, Burpee Seed Farm of Lompoc, Vaca Valley, and Kenwood each with .13 per cent, and El Verano, Santa Maria, Chico, Yountville, and Chino each with .11 per cent. Newcastle soil has .10 per cent, while all others have less.

Nine of the soils have but .01 per cent of humus-nitrogen in the first foot, seven have but .02, forty-six or nearly half of the columns have less than .05 per cent, and hence are much below the desirable percentage of nitrogen. The average of the first foot of all of the columns, excepting the marshes, is about .05 per cent.

Some of the upland soils are quite rich in organic nitrogen in the *upper three feet*, the true soil mass of the arid region. The adobe of Berkeley is the richest with its .13 per cent or approximately 15,000 pounds per acre in a depth of three feet. Eight columns have averages of .10 and upward, viz, the two Arroyo Grande soils, Gilroy, Chico, Farmington, Kenwood, Newcastle, and Cottonwood. Thirty-one columns have averages of from .06 to .10 per cent, all others being below this amount. In other words, we find that more than half of the columns have in their upper three feet less than the .05 per cent of organic nitrogen which is considered necessary for fertility. Many have but little more than traces of the same.

In the entire columns of twelve feet we find that there are eleven upland localities that have averages of as much as .05 per cent, and among these, Berkeley and Arroyo Grande columns stand highest, with averages of .08 per cent or approximately 38,000 pounds of organic nitrogen distributed through the depth of twelve feet.

Humus-phosphate in the Soil.

When vegetable matter is humified in the soil the phosphoric acid of the plant remains in combination in the humus and that of the soil is also attacked: this humic phosphoric acid is considered as more available to plants than that in the soil. It is probable that all humus contains phosphoric acid, but the amount varies very greatly; in some soils the percentage of humus-phosphate is quite large and adds greatly to the fertility of the soil. In seven of the soil columns of the State the percentage of humus-phosphate in the soil was ascertained through the entire column, but the chief interest lies in the amount contained in the upper three feet, the range of annual plant roots. These results are given in the following table:

	Phos- phoric acid in soil, per cent	In surface foot			In upper 3 feet		
		Humus, per cent	Humic phosphoric acid		Humus, per cent	Humic phosphoric acid	
			Per cent	Pounds per acre		Per cent	Pounds per acre
Yuba City clay loam-----	.18	1.27	.05	2,000	.93	.04	4,800
Chico alluvial soil-----	.09	1.84	.05	2,000	1.39	.04	4,800
Stockton adobe clay-----	.06	1.16	.05	2,000	.81	.03	3,600
Modesto sandy soil-----	.11	.37	.01	400	.28	.01	1,200
Russian River alluvium-----	.18	1.30	.07	2,800	1.25	.08	9,600
Santa Clara adobe clay---	.12	4.43	.07	2,800	3.63	.04	4,800
Santa Paula clay loam----	.12	1.23	.07	2,800	1.04	.06	7,200

The Russian River alluvium and the Santa Paula clay loam are quite high in their percentages of humic phosphoric acid in the upper three feet; they approximate 3,200 and 2,400 pounds per acre for each foot in depth; an amount amply sufficient to supply the needs of crops for many years. In the upper six feet of soil the Santa Paula, Santa Clara and Russian River columns have each .05 per cent, or approximately 2,000 pounds of immediately available phosphoric acid in each foot.

These high percentages of humic phosphoric acid, with corresponding percentages of humic potash and humic nitrogen throughout these depths of twelve feet are strong reasons why deep-rooting of plants and trees should be encouraged by a deep water supply and deep cultivation or plowing.

Comparison of Arid and Humid Soils.

A comparison between the soils of the arid and humid regions brings out the very great advantages possessed by the former, and especially by those of California, over the humid, as shown in the first part of this bulletin. But it is especially marked in the amount and distribution of humus in the soils of the respective regions.*

*It has been a rather difficult matter to secure data on humus in the soils east of the Mississippi River for the reason that in their analyses some of the chemists have failed to separate it from the percentage of aggregate "organic matter."

The general average in 280 soils of the humid portion of the United States is 2.63 per cent, and if we add to this the 5.26 per cent in eleven tropical soils of Hawaii, the average is brought to 2.73 per cent or approximately 109,200 pounds per acre.

The average of the 331 California soils and 44 from Idaho, Arizona, and Oregon is 1.28 per cent for the surface foot, or less than one half that of the humid region. For the first foot of the 109 soil columns the average is 1.35 per cent.

But the depth of soil in which most of the plant roots are held and in which the humus color is most pronounced is three feet, and taking this as the true soil of California we find that there is a sum of 3.17 per cent, or an average of 1.06 for each foot; this is equivalent to about 126,800 pounds per acre. To this should be added the percentages of humus found at lower levels of the soil, as shown in the averages of the 109 columns given in the accompanying table, which would bring the total humus to 234,000 pounds in 12 feet.

AVERAGE OF HUMUS IN

	Arid soils		Humid soils, 291 soils, general, per cent
	109 California soil columns, per cent	342 soils, general, per cent	
1-foot soil	1.35	1.28	2.73
2-foot soil	1.04	?	?
3-foot soil	.78		
4-foot subsoil	.62		
5-foot subsoil	.45		
6-foot subsoil	.36		
7-foot subsoil	.30		
8-foot subsoil	.26		
9-foot subsoil	.21		
10-foot subsoil	.18		
11-foot subsoil	.14		
12-foot subsoil	.14		
Sum of per cents in 12 feet	5.83		
Sum of per cents in 3 feet	3.17		
Nitrogen in humus, 3 feet	5.60		
Nitrogen in soil, 3 feet	.05		

The amount of humus then in the average of California soils (3 feet deep) is greater than in those of the humid region; and for the depth of twelve feet it is more than twice as great.

The determinations of humus-nitrogen in the soils of the humid region have been so few and miscellaneous that it is not advisable to deduce from them an average to represent the whole region.

Arid California with her deep soils of well diffused humus and richness in plant food thus possesses very great advantages over the more humid East, where a depth of six to nine inches is very generally accepted as that of a true upland surface soil, containing practically all of the humus and marked by a very sharp change of the black humus color to the gray and yellow subsoil with its inappreciable amount of

humus.* In the sediment lands of the streams and some of the black prairies the humus is of course found at a greater depth.

CONCLUSIONS.

1. The depth of the soils of California is indefinite because of the presence of humus to and beyond twelve feet below the surface. The upper three feet may, however, properly be called the soil, for within that depth the greater part of the feeding roots of plants are found. The sharply defined change of the black humus color to gray at 6 or 9 inches that marks the depth of humid soils, is present in some of the heavy clay soils in California at the depth of three feet; but for the most part the change in tint is very gradual downward through many feet.

2. The soils of California are richer in humus than has generally been supposed; in their depth of three feet (the soil proper) they contain more than in the humid soils, and in the entire columns of twelve feet or more they have double that of the humid soils.

3. The humus in California soils is usually distributed through depths of twelve or more feet, the highest percentage being in the upper three feet and diminishing downward, as shown in each of the 109 soil columns taken from the several agricultural regions; as much as .41 per cent was found in the fifteenth foot of the Fort Romie column, and .74 per cent in the thirteenth foot of that of Davis and Hayward; water was reached in each case.

4. The surface soils of California have an average of 1.28 per cent of humus, as shown in the analysis of several hundred samples taken from the many agricultural regions of the State. This is not sufficient to maintain good tilth in the soil; but as supplemented by that of many feet below, often affords a fair supply of nitrogen. The upper three feet of soil proper have an average of 1.06 per cent per foot, or a sum of 3.17 per cent.

5. The tule swamps have the highest percentage of humus because of the mass of decaying roots and other vegetable matter, while the deserts have the least.

6. Humification is retarded in close compact adobe clays, and the amount of humus is less than in lighter loam and sandy soils.

7. The valleys of the Coast Range in the western part of the State have higher percentages of humus in their soils than have any of the other agricultural regions, probably because of the greater humidity of the climate of that region, and a denser vegetation.

*See Hilgard's Soils, page 164, and Agricultural Science, 1892, page 263; King's The Soil, page 29; Hall's Soils, page 45; Minn. Bulletins 30, 41 and 65 contain analyses of 121 subsoils, in only 16 of which is humus reported though found in all of the corresponding surface soils which were taken to depths of nine inches. (Bulletin 30, page 164.)

8. Arid soils have an immense advantage over those of the humid region of the United States because of this distribution of humus and its nitrogen through a depth of many feet; as it gives a greater depth of soil and induces a deeper root penetration for plants and trees into a greater feeding area and where there is more moisture. The wonderful endurance of drought on the part of plants on California soils is due to this.

9. Humus contains nitrogen in combination, the amount depending on the source of the humus. The average percentage in the humus of the first foot of the soil columns is 5.92 per cent; that of each of the upper three feet is 5.60, and a little less for the entire twelve feet in depth. It varies from one to twenty per cent in individual soil layers.

10. The organic nitrogen in the soil derived from the humus and dependent on the amount of the latter, varies from almost nothing in the lower depths of the soil to as much as .13 in the upper three feet. The average for the first foot of the soil columns is .07 per cent; for each of the three upper feet, the range of most annual plant roots, it is .05 per cent. The investigations of Professor Lipman of this station show that nitrifying bacteria are present and active in California soils to a depth of six feet, and ammonifying bacteria are present through a depth of twelve feet; thus making available to plants the nitrogen content of the humus to these depths.

11. The humus of the soils of this State is very generally derived from plant roots, instead of from accumulations of vegetable material at various depths as the soil was being built up; thus showing that these plants have for ages been deep-rooted.

12. The black color of a soil is not always due to a high humus content; many black soils have a smaller percentage of humus than soils of a gray color. In one instance a very black clay soil from the Santa Clara Valley contained no humus, its color being due to the presence of a black mineral.

13. Humus contains soluble mineral plant food in combination, the phosphoric acid being present in the humus of California soils to the extent of from .01 per cent to .08 per cent throughout the entire depth to which humus reaches, though usually greatest in the upper few feet.

14. Humus is sometimes less in the first foot than in the second, because it is gradually destroyed by cultivation and summer-fallowing of the soil; but may be replaced and increased by proper methods of green-manuring, or the turning under and humification of green crops, preferably legumes.

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